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U. S. DEPARTMENT OF AGRICULTURE.

BUREAU OF PLANT INDUSTRY—Circular No. 109.

B. T. GALLOWAY, Chief of Bureau.

MISCELLANEOUS PAPERS.

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Issued January 4, 1913.



BUREAU OF PLANT INDUSTRY.

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[Cir. 109]

UNITED STATES OFFICIAL COTTON GRADES.¹

By N. A. COBB, *Agricultural Technologist in Charge of Agricultural Technology and Cotton Standardization and Grading Investigations.*

AUTHORIZATION AND SALE OF STANDARD COTTON GRADES.

The appropriation bill for the Department of Agriculture for the year ended June 30, 1909, authorized the fixing of a standard of middling cotton and, using the same as a basis, the establishment of nine grades of cotton, to be designated—

Middling fair.	Strict good middling.	Low middling.
Strict middling.	Middling.	Strict good ordinary.
Good middling.	Strict low middling.	Good ordinary.

The Secretary of Agriculture was authorized to call to his assistance expert cotton classers, and he was directed to prepare copies of the official standard in practical form for distribution at cost.

The Secretary convened in Washington a committee of prominent cotton growers, dealers, manufacturers, and experts in February, 1909, and after due deliberation the committee submitted a unanimous report, together with a set of grades which they had prepared in accordance with the wording of the appropriation act. This report was approved by the Secretary.

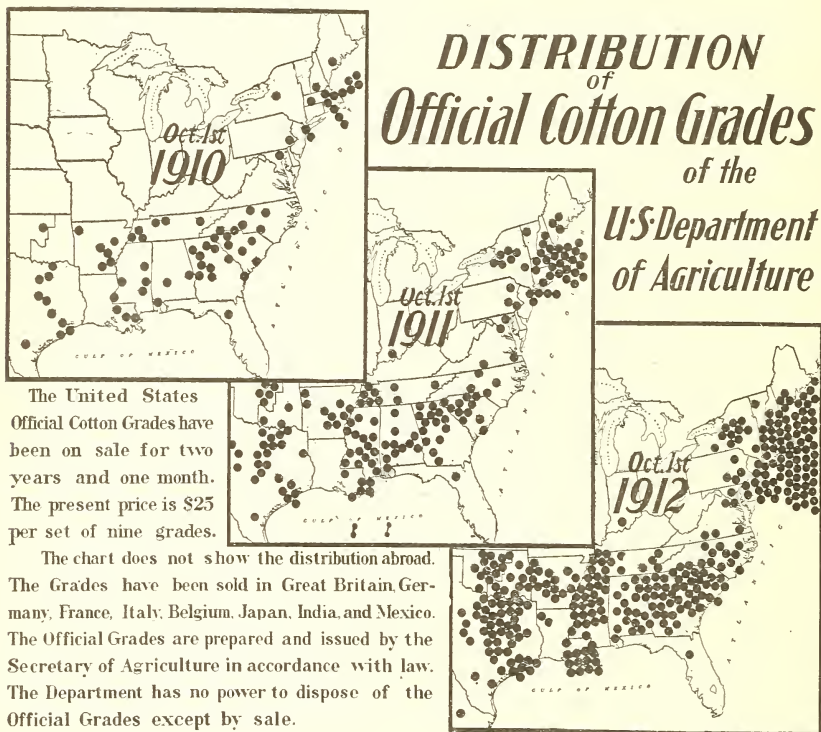
To familiarize the public with the official grades, copies of them were temporarily placed with a number of associations, exchanges, colleges, and other organizations for examination. Within six months after their promulgation sets had been purchased by cotton exchanges, cotton mills, and textile schools in 21 States, as well as in England, Germany, and Mexico. The sales of the grades have doubled in each succeeding year, so that at the present time they are distributed in 40 States and 10 foreign countries, and have been officially adopted by the following cotton exchanges and associations:

New Orleans.	Little Rock.	New England Buyers.
Memphis.	Galveston.	Arkwright Club.
St. Louis.	Macon.	Southern Cotton Buyers.
Charleston.	Mobile.	Fall River Cotton Buyers.
Natchez.	Oklahoma.	

¹ Issued Jan. 4, 1913.

The grades are in use in a number of other associations that have not gone through the formality of adopting them by vote. The accompanying chart indicates the distribution of the grades up to the 1st of October, 1912.

The original set of standards was prepared by experts under the direction of the committee referred to, and from this set the copies for sale have been made by experts from time to time, as required. The original cost of preparing a complete set of the grades was \$35, but within the past year it has been reduced to \$25. A set



of the grades consists of 9 boxes, each containing 12 samples, separately packed, which show the range of diversity within the grade. In the top of each box is a photograph showing the appearance of the cotton when certified by the Secretary. Fractional sets are sold practically pro rata.

PERMANENCY AND VALUE OF STANDARDIZATION.

One of the problems which confronted the department at the beginning was the preservation of the grades as originally prepared by the committee, and numerous experiments were made to determine the best plan to be followed. The experiments indicated that

by the use of large vacuum tubes the cotton types could be kept without appreciable change for an indefinite period of time. Fifty sets of the grades have been put up in vacuum tubes and stored for future use. Each separate sample in each grade was placed in a vacuum tube, making 12 tubes for each grade, or 108 for a complete set. The cotton is first wrapped in chemically pure white paper and then in pure black paper, before being placed in the tube, and in the top of the tube, after the insertion of the wrapped cotton, a 2-inch layer of specially prepared asbestos is placed. The air is then exhausted and the tube sealed by fusing off. No such system has ever before been put into effect in connection with cotton grades or any other graded agricultural product. This is probably one of the largest undertakings of the kind ever attempted.

From time to time one of these vacuum sets will be broken open and replaced in grade boxes, each sample having been specially prepared and labeled with that end in view. In this way absolutely exact copies of the original types will be available from time to time for the next 100 years or more, and cotton grading will, for the first time, be freed from the drawback of depending solely on the memory of experts.

A campaign to educate the producers and local buyers in the use of the grades has been carried on through the agents in charge of the Farmers' Cooperative Demonstration Work. Several of the agricultural colleges are now teaching cotton grading at their summer schools, as well as during the regular term, and are using the official grades as the basis of instruction. With the return of the students to the farm a demand for the grades for use on the farm is bound to grow. With the increasing quantity of cotton which is now sold by the grower directly to the mill, the value of the grades is increasing, all branches of the industry, producer, merchant, and manufacturer alike, using a uniform standard whose correctness and constancy are guaranteed by the Government.

When the original set of types was prepared by the committee appointed for the purpose, the aim was to produce a set which would be representative of American white cotton as a whole. No attention was paid to the source from which the cotton came, and this policy has been continued in the preparation and sale of copies of the original types. The committee had before it an exceedingly great variety of American cotton. Not only did the department secure, through the officials of about 30 American cotton exchanges, grade types in accordance with the ideas of those exchanges and place these entirely at the disposal of the committee, but members of the committee were invited to bring with them cotton which they considered would be suitable for the preparation of the official grades.

A number of members provided cotton in accordance with this invitation. It is safe to say that the committee's attempt to make a set of grades that would apply to the whole of the American cotton belt was so sincere and so adequately backed up by suitable material from which to prepare the grades that the result was all that could possibly have been expected.

During the past few months an effort has been made to ascertain what proportion of the 1912 crop is classifiable on the basis of the present official grades. From a collection of many hundreds of samples taken at random from various parts of the cotton belt, very little cotton has been secured which was not readily classifiable on the basis of the present official grades.

There is a tendency toward the increased use of cleaning machines as adjuncts to ginning machinery. These cleaning machines remove trash and dirt and thus raise the grade of the cotton, so that in the future we may expect more and more cotton to fall into the higher grades, where there is less difference between the cottons from various parts of the country. This tendency toward cleaner cotton will doubtless facilitate the use of the official grades.

It is important to keep in mind that many people, in the practice of grading cotton, are influenced, consciously or unconsciously, by other factors than the color and the amount of trash. Where such a practice prevails, a sample of cotton that on the basis of color and trash would pass as official middling, may pass as of a higher grade, if the staple is unusually good. It is believed that such grading can result only in confusion and that length of staple should be entirely dissociated from the official grades.

FURTHER WORK IN CONTEMPLATION.

The officers of the department are carefully investigating the various problems connected with the question of cotton standardization, and whenever the time seems ripe for further steps toward the establishment of universal cotton grades the department will be equipped and ready to give all the assistance possible.

If the plan of establishing standards for the grading of American cotton is to be brought to a successful issue, it is of the utmost importance that the foundations upon which these standards rest shall be secure. The firmest foundation possible will be that which is in thorough accord with present practices, and the wish of the officers of the department is that no mistakes be made in this fundamental work. If a foundation can be laid which meets with universal approval there is not the slightest doubt that there can be built upon it a system of cotton standardization which will be of great service throughout the cotton industry.

POTATO LEAF-ROLL.¹

By W. A. ORTON, *Pathologist in Charge of Cotton and Truck Disease and Sugar-Plant Investigations.*

INTRODUCTION.

The years 1911 and 1912 have been marked by the prevalence of potato troubles in some of our Western States more serious than any hitherto experienced. Such heavy losses have resulted, particularly in eastern Colorado and western Nebraska, that the production of potatoes, generally one of the most profitable crops for these irrigated districts, has been rendered so uncertain that the growers have been compelled to greatly curtail their acreage.

The Bureau of Plant Industry has nearly ready for publication a bulletin on these new diseases, but as this will necessarily be somewhat technical in character and not available for distribution until later in the season, this paper is issued for the information of the potato growers in the districts affected.

The identification of the disease responsible for the decrease in potato production in the country east of the Rocky Mountains and west of the one hundredth meridian has been in doubt until recently. It was at first thought to be an aggravated form of diseases already known, *Rhizoctonia*, stem-blight, and *Fusarium* wilt, but it is now considered a new and distinct malady called "leaf-roll." This has been common in Europe since 1905, but has not hitherto been identified in the United States.

DESCRIPTION OF LEAF-ROLL.

As indicated by the name, leaf-roll is marked by an upward rolling of the leaves on their midrib. There is usually a pronounced change in the color of the foliage to a yellow, unhealthy shade, often tinged reddish or purplish.

The disease may start early in summer and be far advanced by the end of July. The plants do not die quickly, as they do when attacked by *Fusarium* wilt, but may live nearly as long as healthy ones. The growth is checked and the formation of tubers prevented. Often no potatoes are set, or only small ones clustered around the

base of the stem, while numerous rudimentary tubers are formed on the stolons.

The browning of the woody part of the potato stem and the presence of a brown discolored ring at the stem end of the tubers is not so much a character of the leaf-roll, but is rather to be taken as an indication of the presence of another disease, the *Fusarium* wilt.

The formation of aerial tubers is sometimes a feature of leaf-roll, but in other cases is the result of stem cankers caused by the fungus *Rhizoctonia*.

Leaf-roll is considered to be hereditary through the seed potatoes; that is, if potatoes borne on plants affected by leaf-roll are planted the resulting crop will be diseased and usually much worse than the first crop.

The cause of leaf-roll remains unknown, though it has been prevalent in Europe since 1905 and has been given much study there. It is now believed to be a physiological disorder rather than one caused by a parasite. Many consider it due to some unfavorable soil or climatic condition, but no one has been able to show what conditions produce it or how it may be controlled by any cultural practices.

LEAF-ROLL AN UNSOLVED PROBLEM.

No fully satisfactory remedy for leaf-roll has been discovered. It presents one of our most serious problems for investigation and one which it is hoped to push actively as soon as means are provided. We have, however, the benefit of seven years of German experience with the same trouble. The anxiety caused by its appearance in Germany has been somewhat allayed with the passage of time, and the best authority on potato diseases there even states that through the awakening of interest in better culture and in improvement of seed the leaf-roll will prove in the end a benefit to German agriculturists and their potato production will be permanently increased.

CONTROL MEASURES.

While we can not recommend any preventive treatment with the confident assurance that it will be successful, there are some points of attack that are strongly to be recommended as having given the best results elsewhere and as being common-sense measures whether disease is present or not. Most important of these are *good seed*, *crop rotation*, and *improved culture*.

The seed problem takes first place in any movement for the betterment of our potato industry and particularly in these western districts, where diseases are extensively carried on seed. While there may be occasional apparent exceptions, it is the general rule that *seed from fields affected by leaf-roll will give a diseased crop*. It is

therefore strongly to be recommended that no seed be planted except that known to come from healthy fields. If there are none in the neighborhood, seed should be brought in from outside. Leaf-roll is not known to occur in Minnesota, Wisconsin, or Michigan.

The expense of bringing seed from distant points and the uncertainty of getting a vigorous stock of the variety desired emphasize the great need of a better organization of the potato growers for seed selection and inspection. It should be possible to buy seed potatoes accompanied by a certificate from a reliable authority that they are free from disease and of the variety claimed. Such certification should be based on a field inspection made in early autumn, when the foliage is still alive. Leaf-roll can not be detected by an inspection of the tubers.

In purchasing seed potatoes, those infected with *Fusarium* wilt should also be avoided. Any lot where many tubers show a brown, discolored ring when cut across the stem end should be discarded.

Crop rotation is absolutely essential to permanent potato culture. It is a common practice to grow several successive crops in new western land, but this always has one inevitable result—diseases are introduced and spread until it is no longer possible to grow potatoes with profit. Must every community and every farmer learn this lesson separately, or will the experience of the many profit the remaining few?

There is abundant land in every irrigated district for a long rotation, and particularly at this time when so few potatoes are being planted it is possible to put them on land that has not been in this crop for four or five years.

Cultural methods may reduce the injury from leaf-roll and other diseases. No pains should be spared to give the potato crop the care and attention needed for its most favorable development. Some of the most essential points are given by Prof. L. C. Corbett in Circular No. 90 of the Bureau of Plant Industry, as follows:

PREPARATION OF LAND.

Since the potato is a deep-rooted crop and forms its tubers beneath the soil, it stands to reason that it requires a much deeper seed bed than will be necessary for cereal crops. In fact, the preparation for potatoes should be as deep and as thorough as for sugar beets, whether in the irrigated or in the humid region. If a preparatory crop, such as alfalfa or clover, is to be turned under for potatoes, it is advisable to plow this crop under in the fall and to compact the soil sufficiently to make it a good retainer for water, but not so smooth that it will blow. Before planting in the spring the land should be made fine to a depth sufficient to admit of planting and cultivation. If unusually dry the land should be irrigated before the crop is planted. If the normal precipitation has occurred during the winter and spring months, the crop may be planted without irrigation. It is not advisable, however, to plant the crop in dry, hot earth and to immediately irrigate it. Irrigation should precede rather than follow

the planting. If the crop does not grow rapidly after planting, irrigation should be provided from time to time as the appearance of the crop and the condition of the soil would indicate; a dark-green or blackish color shows a lack of moisture on the part of the plants, while light-green or yellowish tints indicate the presence of too much moisture. The plant should be kept growing at the maximum rate from the time it appears above the ground until it has completed its season's work, and cultivation supplemented by irrigation must be relied upon to keep the plant working.

METHOD OF IRRIGATION.

The water for irrigating potatoes is best applied in every other furrow, the furrows being narrow and deep and the water so applied that the ground will not be saturated above the point where the tubers are formed. This will induce the formation of a deep instead of a superficial root system. In order to accomplish this the rows must be sufficiently wide apart to admit of throwing up broad high ridges, with narrow deep furrows between, in which the water can be led in a small stream for a long period rather than by means of a large stream flowing only for a short time. The successive irrigations should be carried on in alternate rows; the second irrigation should be in the rows not used by the first, and the third in the rows used during the first. Cultivation should follow irrigation as quickly as the condition of the soil will permit, but as soon as the tubers have made their growth, usually about September 1, water should be withheld, so that the soil will dry and the crop ripen in proper condition for harvesting.

[Cir. 109]

MORPHOLOGY OF COTTON BRANCHES.¹

By O. F. Cook, *Bionomist in Charge of Crop Acclimatization and Adaptation Investigations.*

INTRODUCTION.

The cotton plant has two distinct kinds of branches, differing in position, structure, and function. The upright "limbs," or vegetative branches, behave like the main stalk of the plant and do not produce flowers or bolls. The floral buds appear on horizontal fruiting branches. The specialized habits of growth are of interest from the general standpoint of morphology, as well as in their applications to cultural and breeding problems. The practical considerations have been treated in several publications of the Bureau of Plant Industry.²

POSITIONS AND HOMOLOGIES OF BUDS.

The positional relations of the two types of branches have seemed to throw the clearest light upon their structural homologies. It is easier to determine the positions of the buds from which the branches develop than to understand the relations of the mature branches. In addition to the bud that serves to continue the growth of the shoot, each internode of the cotton plant produces two other buds, one in the axil of the leaf and another to the right or left of the axil. Some stalks are right handed and others left handed with respect to the position of the extra-axillary buds and the branches produced by these buds.

The axillary buds usually remain dormant, but may be developed into vegetative branches when the conditions are favorable to luxuriant growth of the plants. The fruiting branches arise from the extra-axillary buds of the main stalk and the vegetative branches. The floral buds are also developed in the extra-axillary position on the fruiting branches. Thus the floral buds of the fruiting branches have been considered homologous with the extra-axillary buds that give rise to the fruiting branches. The axillary buds of the fruiting branches are able to produce vegetative branches, like the axillary

¹ Issued Jan. 4, 1913.

² Weevil-resisting adaptations of the cotton plant, Bulletin 88. A study of diversity in Egyptian cotton, Bulletin 156. Dimorphic branches in tropical crop plants: Cotton, coffee, cacao, the Central American rubber tree, and the banana, Bulletin 198. Arrangement of parts in the cotton plant, Bulletin 222. Dimorphic leaves of cotton and allied plants in relation to heredity, Bulletin 221. The branching habits of Egyptian cotton, Bulletin 249.

buds of the main stalk. The functional specialization of the branches of the cotton plant is much less complete than in coffee and cacao, where one form of branches is unable to regenerate the other form.

A SYMPODIAL THEORY OF THE FRUITING BRANCHES.

Another interpretation, advanced by Mr. H. M. Leake, of Cawnpore, India, makes the two kinds of branches appear much more fundamentally different. According to Leake the vegetative branches are monopodial and the fruiting branches sympodial. This means that a vegetative branch is looked upon as a single continuous shoot, while a fruiting branch is supposed to be composed of a succession of independent shoots, each represented by a single internode and terminated by a flower. Thus, the floral buds of the joints of the fruiting branches would correspond to the terminal buds of the vegetative branches or of the main stalk.¹

The structure of the fruiting branches and the nature of the differences between the two kinds of branches are matters of special interest, because Leake has reported Mendelian reactions in crosses between varieties with different habits of branching. Varieties with many vegetative branches on the main stalk are described as monopodial, while the varieties with only a few vegetative branches are called sympodial, and the two characters are supposed to reappear in definite proportions of the hybrid progenies. These results have been accepted by Bateson and used as one of the chief illustrations of the practical importance of the Mendelian methods of breeding hybrid varieties.²

INFLUENCE OF ENVIRONMENT ON HABITS OF BRANCHING.

The same characters that have appeared to Mendelize in India have shown in the United States a wide range of environmental modification. Varieties that would be considered sympodial under some conditions become altogether monopodial under other conditions. When the conditions keep the plants small, only a few of the vegetative branches are produced or none at all; but when the conditions favor luxuriant growth the fruiting branches may be replaced or transformed into vegetative branches. Even under the same conditions in other respects it is possible to control the development of the branches by different methods of thinning. Plants that are thinned early, so as to stand far apart during the earlier stages of growth, are likely to show a much greater development of the vegetative branches than plants that are left closer together. In some varieties of cotton the number of vegetative branches may be in-

¹ Leake, H. M. Studies in Indian cotton. *Journal of Genetics*, v. 1, p. 205, 1911.

² Bateson, W. *Genetics*. *Popular Science Monthly*, v. 79, p. 319, 1911.

creased by the growth of more of the axillary buds into branches, but in most cases the additional vegetative branches are produced from extra-axillary buds that under other conditions would have developed into fruiting branches.

The nature of the differences between the two kinds of branches must be understood before either the Mendelian reactions or the environmental transformations can be appreciated. Though there is nothing inherently improbable in the idea that the same character may show both kinds of reactions, such cases would not be expected under the Mendelian theory of heredity as a process of alternative transmission of "unit characters." It would not be expected that a character which behaved as a pure recessive in a Mendelian experiment could be called forth by a change of external conditions. Yet this possibility seems to be indicated by the variations that have been observed in the branching habits of cotton.

RELATIONS OF FLORAL BUDS TO STIPULES.

Though a casual examination of the cotton plant may appear to support the theory that the fruiting branches are sympodial, there are several facts that seem to forbid the acceptance of this view. The relations of the floral buds to the adjacent parts of the fruiting branches do not warrant the conclusion that the floral buds of the fruiting branches correspond to the terminal buds of the vegetative branches or of the main stalk.

If the floral buds of the horizontal branches were homologous with the terminal buds of the upright shoots, they should have the same symmetrical position in relation to the stipules. But instead of standing midway between the stipules the pedicel of the floral bud is always nearer to one of the stipules than to the other. The leaves of the main stalk and vegetative branches have equal stipules, but on the fruiting branches the stipules are generally unequal. The inequality is especially pronounced in Egyptian cotton, where one of the stipules is often more than twice as wide as the other. In all cases the more enlarged stipule subtends the floral bud and frequently shows a slight attachment to the base of the pedicel.

A STIPULAR RIM ON FRUITING BRANCHES.

Another peculiarity of the fruiting branches, shown especially in the Egyptian cotton, is a narrow rim, or collar, that connects the bases of the stipules, so that the base of the leaf may be said to encircle the branch. This is not true of the leaves of the main stalk, where the stipules become much more widely separated, with no indication of a connecting rim. These differences may be ascribed to the fact that the thickening of the joints of the fruiting branches is not symmetrical

in relation to the base of the leaf. The fact that no stipular rim appears on the main stalk or vegetative branches doubtless results from the fact that the principal thickening of the vegetative shoots takes place in the segment of the stalk that is more directly between the stipules, whereas on the fruiting branches the first thickening is chiefly on the side that has the enlarged stipule.

POSITIONS OF FLORAL BUDS.

The chief reason for the sympodial theory of the fruiting branches of cotton is doubtless to be found in the fact that the flowers and fruits appear to stand opposite to the leaf of the same node, as in other plants that have sympodial habits of growth. But closer attention to the cotton plant will make it apparent that the floral bud is not directly opposite to the base of the petiole of the leaf. When younger joints of the fruiting branches are examined, the floral buds are found closer to the axillary buds—that is, more nearly in the position of the extra-axillary buds of the main stalk and the vegetative branches.

The floral bud appears to have the terminal position because the true terminal bud remains relatively undeveloped until the growth of the floral bud is well advanced. The fruiting branches might be said to grow a joint at a time by successive enlargements of basal internodes of a small terminal shoot. The accelerated development of the floral bud leaves the terminal bud at one side with the axillary bud. But the apparently terminal position of the floral bud is lost when the base of the next joint thickens to its full size. This pushes the pedicel farther away from the original insertion next to the axillary bud and also brings it into a more erect position at an angle with the branch. When the terminal bud is aborted, as often happens, the pedicel of the last flower or boll remains in line with the last internode of the branch.¹

The idea of sympodial branching might be strengthened by cases where the pedicel is abnormally short and thick or where the development of the next internode occurs too late to push the pedicel out of line. A still closer approximation to the sympodial condition would be reached if an aborted terminal bud of a fruiting branch were replaced by the development of an axillary bud. This probably occurs in some cases, though examples have not been observed thus far. The axillary buds are usually aborted with the terminal buds,

¹ The relative rates of growth of the floral buds and the adjacent terminal buds or young shoots will probably be found to differ in the various species and varieties of cotton, like other characters. It was noticed by Mr. G. N. Collins, of the Bureau of Plant Industry, in a variety of Sea Island cotton growing at Tuxtla, Mexico, in January, 1907, that all of the involucre had one of the bracts with a deep channel or reentrant angle on the side next to the terminal shoot. It has also been observed by Mr. Rowland M. Meade, of the Bureau of Plant Industry, that the bract on the side toward the terminal shoot is usually smaller than the other bracts of the same involucre. See "Arrangement of parts in the cotton plant," Bulletin 222, Bureau of Plant Industry, U. S. Department of Agriculture, 1911.

and this is especially likely to occur on the shortened fruiting branches of small plants or at the end of the season when growth has nearly ceased. In connection with the bractlike leaves of abnormally shortened fruiting branches both the axillary and the terminal buds are sometimes completely suppressed, as in the axils of the bracts of normal involucre.

TRANSFORMATION OF FRUITING BRANCHES INTO VEGETATIVE BRANCHES.

Even on normal fruiting branches the pedicels of the floral buds are not turned aside far enough to bring the successive joints of the branches entirely into line, which accounts for the characteristic zigzag form of the fruiting branches, but when the floral buds are aborted at a very early stage the branches are able to grow straight, like the vegetative branches. Such transformed branches may show the scars of aborted floral buds on a few of the lower joints, while the upper joints are without scars and are as straight and upright as normal vegetative branches. This is one of the ways in which fruiting branches are transformed into vegetative branches, but such cases of transformation during the growth of the branch are seldom found. The transformations usually occur at earlier stages of growth, before the formation of any floral buds, even on the basal joints. On normal fruiting branches the basal internode is longer than the others, whereas vegetative branches often have short internodes at the base; but some branches are intermediate in this respect, as well as in other characters.

Individual plants with branches of intermediate form have been found in unacclimatized stocks of Kekchi and other imported types of cotton. Though behaving as vegetative branches in other respects, an abortive floral bud appears at each node throughout the season. On some plants all the buds are shed while still very minute, while on other plants the buds reach more advanced stages of development. The closer the approach of the plants to normal fertility the more zigzag the branches become. The occurrence of such transformations and in such various degrees does not indicate that the two forms of branches are so fundamentally different as the sympodial theory would imply.

SUCCESSIVE GROWTH OF INTERNODES OF VEGETATIVE SHOOTS.

That the zigzag form of the fruiting branches may be due to the accelerated growth of the floral buds is also indicated by a similar tendency in rapidly developing terminal shoots of main stalks or vegetative branches, especially on large luxuriant plants. Here the joints also appear somewhat zigzag at first, apparently because the

young leaf and the fruiting branch of each internode have a period of very rapid growth when they take nearly upright positions and throw the delicate terminal shoot out of the perpendicular. The petiole of a young leaf often becomes thicker, for a time, than the next joint of the stalk. Subsequent thickening of the joints pushes the leaves and branches over to the side, so that the zigzag form of the young terminal shoots is gradually lost and the mature stalk becomes straight and upright. In cluster varieties the mature stalks may still show the zigzag form, which is doubtless connected with the fact that such varieties have an accelerated development of short, thick fruiting branches. Thus, if the zigzag form were to be accepted as a sufficient indication, the main stalk might be considered sympodial as well as the fruiting branches, but there is no occasion for such a theory, in view of the fact that the main stalk has no floral buds or branches opposed to the leaves.

CONCLUSIONS.

There is no apparent necessity to consider the normal development of the cotton plant as resulting in any truly sympodial structure. The pseudosympodial form of the fruiting branches arises from the fact that a flower, instead of a branch, is developed from the extra-axillary bud, and from the further peculiarity that the fruiting branches have a stronger tendency to develop one joint at a time. But notwithstanding these differences the two kinds of branches may be considered as homologous in other respects. The floral buds have an extra-axillary position on the internodes of the fruiting branches, corresponding to the extra-axillary position of the buds that produce the fruiting branches on the main stalk or the vegetative limbs. Transformations of branches from the fruiting to the vegetative form afford additional evidence that the two types of branches are not so fundamentally different as the sympodial theory would imply. Changes from one form of branches to the other are readily induced by differences of external conditions.

[Cir. 109]

THE WILTING COEFFICIENT FOR PLANTS IN ALKALI SOILS.¹

By THOMAS H. KEARNEY,² *Physiologist in Charge of Alkali and Drought Resistant Plant Investigations.*

INTRODUCTION.

In a previous publication of this bureau³ the wilting coefficient was defined as "the moisture content of the soil (expressed as a percentage of the dry weight) at the time when the leaves of the plant growing in that soil first undergo a permanent reduction in their moisture content as the result of a deficiency in the soil-moisture supply. By a permanent reduction is meant a condition from which the leaves can not recover in an approximately saturated atmosphere without the addition of water to the soil." It follows that when the moisture content of a given soil falls below the percentage representing the wilting coefficient, the plants are unable to continue their growth. In the present publication, therefore, the soil water in excess of the wilting coefficient will be referred to as "moisture available for growth."

The term "alkali" is here used in the popular sense to designate those alkali and alkali-earth metals (Na, K, Ca, Mg) which are most frequently present in excess in the soils of arid regions, together with the acid radicles (Cl, SO₄, CO₃, HCO₃) with which these bases are generally associated in alkali soils.

The experiment described in the following pages was designed to ascertain whether an alkali content of the soil not sufficiently high to cause evident injury to the plants would have the effect of raising the wilting coefficient; in other words, whether the plants under such conditions would reach a permanently wilted condition before they had exhausted the soil moisture to a point corresponding to the wilting coefficient as calculated from the moisture equivalent for the type of soil used. It was assumed that if this proved to be the case it would be possible to determine the minimum concentration at which alkali of a given composition becomes the limiting factor for plant growth from the inability of the plants to reduce the soil moisture to the calculated wilting coefficient.

For this purpose it was decided to grow seedling plants of wheat in a series of soil mixtures having a gradually increasing salt content. Each soil was to contain at the outset the same amount of water available for growth—i. e., the same percentage of moisture above the calculated wilting coefficient—and no additional water

¹ Issued Jan. 4, 1913.

² Dr. L. J. Briggs, Physicist in Charge of Biophysical Investigations, Bureau of Plant Industry, cooperated by having the moisture equivalents determined and the soil extracts prepared in his laboratory. The chemical analyses of the extracts were made by Mr. J. F. Breazeale, of the Bureau of Chemistry.

³ Briggs, L. J., and Shantz, H. L. "The wilting coefficient for different plants and its indirect determination," U. S. Department of Agriculture, Bureau of Plant Industry, Bulletin 230, 1912.

was to be supplied. It was believed that this method of experiment would eliminate all varying factors except the salt content of the soil solution. In order to determine whether the plants reduced the moisture content to the wilting coefficient, it was necessary to provide against direct evaporation from the soil during the course of the experiment. This provision also served to reduce to a minimum variations in the concentration of the solution in different portions of the soil mass.

STOCK SOILS USED.

Two natural soils from North Platte, Nebr., one of which had a much higher salt content than the other, were employed. Each was moistened sufficiently to make it easy to handle and was then thoroughly mixed. That a high degree of uniformity was thus obtained is shown by the close agreement of the determinations of electrical resistance, moisture content, and moisture equivalent¹ made on different portions of each stock soil.

The two stock soils had a mean moisture equivalent of 25.5 and 24.1 per cent, respectively, indicating wilting coefficients of 13.8 and 13.1 per cent. They gave, when saturated, a mean electrical resistance of 205 and 38 ohms, respectively.² The total water-soluble material was 0.17 and 1.03, respectively, in percentages of the dry weight of the soil.

The chemical composition of the alkali salts in each of these stock soils is given in Table I, which follows. The data were obtained by analyses of extracts prepared in the ordinary manner for alkali determinations—agitation for 30 minutes with 500 c. c. of water per 100 grams of soil.

TABLE I.—*Chemical composition of the extracts from soils used in the experiment, in percentages of the total solids in the extracts.*

Soil No.	Total soluble (in percentage of dry weight of soil).	Percentages of the total soluble solids.							
		Ca.	Mg.	K.	Na.	Cl.	SO ₄ .	CO ₃ .	HCO ₃ .
78.....	0.17	12.2	5.1	11.5	14.3	2.0	8.7	.....	25.7
79.....	1.03	1.6	.....	6.9	29.2	8.8	44.2	.....	8.4

The composition of the soluble matter was markedly different in these two soils, that which had a low salt content (No. 78) having

¹ The moisture equivalent has been shown by Briggs and McLane (Bulletin 45, Bureau of Soils, 1907) to be an accurate indicator of the moisture-holding capacity of the soil and to be more readily determinable than the moisture capacity itself. As defined by Briggs and Shantz (Bulletin 230, Bureau of Plant Industry, p. 56), it is "the percentage of water which it [the soil] can retain in opposition to a centrifugal force 1,000 times that of gravity." The method followed in determining moisture equivalents is described on pp. 56 and 57 of Bulletin 230. From the moisture equivalent the wilting coefficient can be calculated by means of a formula given on p. 58 of the same publication.

² In the standard container (capacity about 50 c. c.) used in determinations of the salt content of the soil by means of the electrolytic bridge. The apparatus is described by Dr. L. J. Briggs in Bulletin 15, Bureau of Soils, 1899, pp. 32 to 35. See also "The electrical bridge for the determination of soluble salts in soils," by R. O. E. Davis and H. Bryan, Bulletin 61, Bureau of Soils, 1910, wherein tables are given for temperature correction and for computing from the resistance at 60° F. the percentage of salts present.

been absolutely, as well as relatively, richer in calcium and magnesium, but both absolutely and relatively very much poorer in sodium, in chlorids, and especially in sulphates. Soil No. 78 is also relatively richer, although absolutely poorer, in potassium and bicarbonates.

In order to insure as nearly as possible the same percentage of water available for growth in all soil mixtures used in the experiment, sufficient water was added to each stock soil to give them practically the same "available" moisture content. The total water contents attained were 24.4 per cent in soil No. 78 and 23.9 per cent in soil No. 79, which gave available-water contents of 10.6 and 10.8, respectively.

PREPARING THE SOIL MIXTURES.

It was decided to use in the experiment stock soil No. 78 and 14 mixtures of the two stock soils. A graduated salt content in these mixtures was obtained by varying the proportions of the two stock soils. Precautions were taken to reduce evaporation to a minimum during the mixing and subsequent handling of the soils. Determinations of the electrical resistance (in ohms, at 60° F.) and of the total water-soluble material, moisture equivalent, and moisture content (in percentages of dry weight of soil) were made upon each mixture as prepared for planting. These values, together with the initial concentration of the soil solution (calculated from the total water-soluble material and the initial water content), the wilting coefficient (calculated from the moisture equivalent), and the percentage content of water available for growth (by subtraction of the wilting coefficient from the percentage of total water present) are given for each of these mixtures in Table II.

TABLE II.—*Electrical resistance, total soluble material, concentration of solution, moisture equivalent, wilting coefficient, moisture content, and moisture available for growth in the soil mixtures used (means of all determinations).*

Mixing proportions of stock soils.		Soil-mixture No.	Electrical resistance.	Total soluble material.	Initial concentration of solution. ¹	Moisture equivalent.	Wilting coefficient (calculated).	Moisture content.	Moisture available for growth.
78	79								
			<i>Ohms.</i>		<i>Per cent.</i>				
20	0	1	200	0.183	0.75	25.5	13.8	24.4	10.6
19	1	2	165	.222	.94	25.3	13.7	23.6	10.1
18	2	3	136	.236	1.00	25.5	13.8	23.6	9.8
17	3	4	122	.305	1.24	24.5	13.3	23.6	10.3
16	4	5	111	.336	1.42	24.5	13.3	23.7	10.4
15	5	6	99	.365	1.54	24.4	13.3	23.7	10.4
14	6	7	89	.405	1.71	25.0	13.6	23.7	10.1
13	7	8	81	.418	1.76	25.5	13.8	23.7	9.9
12	8	9	76	.488	2.06	25.2	13.7	23.7	10.0
11	9	10	72	.409	(?)	25.0	13.6	23.6	10.0
10	10	11	65	.509	2.14	23.7	12.9	23.8	10.9
9	11	12	62	.627	2.63	24.9	13.5	23.8	10.3
8	12	13	59	.675	2.85	24.5	13.3	23.7	10.4
7	13	14	55	.740	3.15	24.1	13.1	23.5	10.4
6	14	15	50	.759	3.17	23.8	12.9	23.3	10.4

¹ Since the percentage of moisture corresponding to the wilting coefficient for the 15 soils averaged 56 per cent of the percentage representing the initial moisture content and since there was little change in the total salt content of the soils (as shown by determinations of electrical resistance) during the period of the experiment, it follows that the concentration of the solution in each soil had very nearly doubled when the wilting coefficient was reached.

² There was evidently an error here, either in taking the sample or in the determination.

The figures for moisture equivalent in Table II show some irregularities, doubtless attributable to errors in the method of determination. Such errors could be eliminated only by making a larger number of determinations for each soil. The contents of water available for growth in the whole series of mixtures ranged from 9.8 to 10.9 per cent, but these differences were hardly of sufficient magnitude to affect the results of the experiment.

Chemical analyses of extracts from each of these soil mixtures showed, for most components, an increase from mixture to mixture corresponding to the increase of total soluble matter. A noteworthy exception was HCO_3 , of which practically the same quantity was found in all. The mixtures having the lowest total salt content had the highest content of calcium and magnesium, as would be expected from the fact that larger amounts of these bases existed in stock soil No. 78 than in stock soil No. 79.

PLANTS USED AND CONDITIONS OF GROWTH.

Kubanka wheat (Grain Investigations No. 1440) was used, the stock having been the same as that employed by Messrs. Briggs and Shantz in their investigations of the wilting coefficient.

The seeds were placed in moist blotters on April 3; three days later they were in proper condition for planting. While no special effort was made to select seedlings of the same size, none were planted which did not have the plumule and the rootlets extruded. All seedlings planted appeared to be perfectly healthy and had no roots much longer than 1 inch. The seedlings were planted in straight-walled, cylindrical drinking glasses, each holding about 250 grams of soil. Five seeds were planted in each glass and there were six glasses of each soil mixture, making a total of 30 seedlings planted in each soil mixture used in the experiment.

In planting, most of the soil required was placed in the glass and was shaken down by tapping the bottom of the glass on the table. The seedlings, taken directly from the moist blotters, were laid on the loose surface of the soil; the glass was then filled evenly to the brim with the remaining soil, so as to completely cover the seedlings, and the soil was pressed down firmly, first around the edges and then in the center.

The surface was then sealed over with a melted mixture of 80 per cent of paraffin and 20 per cent of petrolatum, as described in a previous publication of this bureau.¹

In order to equalize as far as possible the temperature of the soil in the glasses and to prevent condensation, which would result in an unequal distribution of the water and salts in different portions

¹ Bulletin 230, pp. 10-14.

of the soil mass, the glasses were kept in a partitioned metal tank, through which a stream of water was kept flowing during the whole period of the experiment.¹ A light tent of bolting cloth was stretched over the tank during hours of bright sunlight, in order to prevent, if possible, the heating and melting of the wax seals.²

EMERGENCE OF THE PLANTS.

A record was kept of the rate at which the plants in each glass appeared above the surface of the soil, this record having been based on daily observations during the first 12 days (with the exception of the eighth day after planting) and a final observation on the fourteenth day, after which no more plants emerged. In mixture No. 15 no plants appeared.

Table III shows the total number of plants (out of the 30 inserted) which finally appeared above the seal and the number of days from the date of planting to that when the last plant emerged in each soil mixture.

TABLE III.—Rate of emergence of the plants in the different soils.

Soil-mixture No.	Number of plants that emerged.	Number of days until emergence ceased.	Soil-mixture No.	Number of plants that emerged.	Number of days until emergence ceased.
1.....	30	4	9.....	30	6
2.....	30	4	10.....	30	7
3.....	30	4	11.....	24	10
4.....	30	4	12.....	15	14
5.....	30	4	13.....	23	10
6.....	30	4	14.....	10	14
7.....	30	4	15.....		
8.....	30	4			

The behavior of the plants in the several glasses of the more concentrated soils (Nos. 11 to 14) was decidedly puzzling. In mixture No. 11 all plants emerged in five of the glasses and none in the sixth. In mixture No. 12 all plants emerged in three of the glasses and none in the other three. In mixture No. 13 all plants emerged in three of the glasses, all but one of the plants in two others, and none in the sixth. In mixture No. 14 all plants emerged in two of the glasses and none in the other four. No explanation could be found for these irregularities. Electrolytic bridge readings at the close of the experiment showed that they could not be attributed to differences in salt content of the soil as between the glasses in which growth was made and those in which no plants emerged.

¹ This method is described and illustrated in Bulletin 230, Bureau of Plant Industry, p. 13.

² In spite of these precautions, owing to the rather high temperatures that prevailed during the period of this experiment, some softening and buckling took place in several of the glasses, which made it necessary to break the seals in order to release plants caught beneath them. The seals were repaired so quickly that no appreciable loss of water by direct evaporation could take place. This could have been obviated by using for the seals a composition having a higher melting point.

Nevertheless, the figures given in Table III show clearly a retarding effect of the more strongly saline soil mixtures. Observations at more frequent intervals than every 24 hours might have shown some retardation in mixtures less concentrated than No. 9, although it was noted that emergence was at least as prompt in No. 5 as in Nos. 1 to 4.

CHARACTER OF GROWTH.

On April 13, one week after planting, the longest leaf in each glass was measured and the mean of these values for the six glasses of each soil was taken as expressing the growth made in that soil while there was still abundant "available" moisture. Table IV shows the values thus obtained.

TABLE IV.—*Mean length of the longest leaf in each soil one week after planting.*

Soil-mixture No.	Mean electrical resistance.	Mean length of the longest leaf.	Soil-mixture No.	Mean electrical resistance.	Mean length of the longest leaf.
	<i>Ohms.</i>	<i>Millimeters.</i>		<i>Ohms.</i>	<i>Millimeters.</i>
1.....	200	153.5	9.....	76	81.0
2.....	165	156.0	10.....	72	66.0
3.....	136	138.0	11.....	65	42.9
4.....	122	134.0	12.....	62	29.0
5.....	111	128.0	13.....	59	21.0
6.....	99	121.0	14.....	55	29.0
7.....	89	113.0	15.....	50	.....
8.....	81	96.7			

These data show a much more marked correlation between the rate of growth of the plants and the salt content of the respective soils than the figures relating to rate of emergence given in Table III.

In soils Nos. 1 to 8 the seedlings made a good, healthy growth in all the glasses. In Nos. 9 to 11 their growth was good in the main, but the plants were smaller. In Nos. 12 to 14 the growth was irregular in the glasses in which any plants emerged, some plants having been small and sickly, while others had made a fair growth and appeared fairly normal. For some reason the average growth was better in No. 13 than in No. 12.

DETERMINATION OF THE WILTING COEFFICIENT.

As soon as the plants appeared to be in a wilted condition the soils were collected from the glasses for moisture determination.

Table V gives the final water content of the soil in each glass in which sufficient growth was made to reduce the water content to anywhere near the wilting coefficient, as well as the mean of these determinations for each soil mixture. For comparison, the mean wilting coefficient is given for each mixture, as calculated from the moisture equivalents at the outset of the experiment.

TABLE V.—*Water contents of the soils when plants first appeared wilted, with calculated wilting coefficients of the corresponding mixtures.*

Soil-mix- ture No.	Glass No.	Water content when plants first appeared wilted.		Wilting coefficient (calcu- lated from the moisture equiva- lents).	Soil-mix- ture No.	Glass No.	Water content when plants first appeared wilted.		Wilting coefficient (calcu- lated from the moisture equiva- lents).																
		For each glass.	Mean for each soil mixture.				For each glass.	Mean for each soil mixture.																	
1.....	{ 1 2 3 4 5 6	{ 13.4 13.3 13.2 12.8 13.3 13.4	13.2	13.8	7.....	{ 1 2 3 4 5 6	{ 13.5 13.8 13.4 13.9 13.6 13.2	13.6	13.6																
2.....	{ 1 2 3 4 5 6	{ 15.4 13.7 13.5 14.6 13.9 13.8			14.1	13.7	8.....			{ 1 2 3 4 5 6	{ 13.0 12.8 13.4 13.4 13.3 13.5	13.2	13.8												
3.....	{ 1 2 3 4 5 6	{ 14.2 14.0 14.1 14.8 14.5 14.5					14.3			13.8	9.....			{ 1 2 3 4 5 6	{ 15.2 14.5 14.1 14.4 14.0 13.6	14.3	13.7								
4.....	{ 1 2 3 4 5 6	{ 14.7 14.8 13.8 14.1 14.9 15.1									14.6			13.3	10.....			{ 1 2 3 4 5 6	{ 13.6 14.0 14.1 13.4 14.1 14.6	14.0	13.6				
5.....	{ 1 2 3 4 5 6	{ 14.7 14.0 14.4 14.1 15.0 14.1													14.4			13.3	11.....			{ 1 2 3 4 5 6	{ 14.0 14.2 13.8 13.9 14.7 15.2	14.1	12.9
6.....	{ 1 2 3 4 5 6	{ 14.0 13.2 14.0 13.6 15.2 14.5																	14.1			13.3	12.....		
			13.....	{ 1 2 3 4 5 6				{ 12.8 15.5 13.3 13.3 13.5 14.8	13.7														13.3		
			14.....	{ 1 2 3 4 5 6	{ 12.8 15.5 13.3 13.3 13.5 14.8	14.2		13.1																	

The figures in Table V show the mean water content at the time of apparent wilting to have been higher in most of the soil mixtures than the calculated wilting coefficient.¹ Nevertheless, even in the most strongly saline mixture (No. 14) in which any emergence took place, the plants in at least one of the glasses were able to reduce the moisture content to a percentage agreeing, within the limits of experimental error, with the calculated wilting coefficient.

On the other hand, in glasses where the plants remained very small and sickly this was not possible. Thus, in one of the glasses of mixture No. 13, in which the plants began to die at about the date

¹ Probably because the high temperatures that prevailed toward the close of the experiment made it rather difficult to distinguish between temporary and permanent wilting. More accurate determinations of the permanent wilting point could doubtless have been made if the plants, as soon as they appeared to be wilted, had been transferred to a saturated atmosphere in order to determine whether they could recover their turgidity.

when the wilting coefficient had been reached in the least saline mixtures, the soil-moisture content (determined when it became evident that the plants would make no further growth) was found to be 22.8 per cent. Since the initial water content of this soil was 23.7 per cent and the initial moisture available for growth was 10.4 per cent (Table II), the loss of water by transpiration in this glass amounted to only 3.8 per cent of the total and 8.6 per cent of the available moisture present at the outset.

While the moisture content of all the soils was finally reduced in at least one of the glasses to the wilting coefficient, this happened much more rapidly in the soils which had a high electrical resistance (low salt content) than in those which had a low electrical resistance (high salt content). There was, on the whole, a remarkably close correlation between the salt content of the soil and the length of time required for the plants to reach a wilted condition. The relation is expressed in Table VI.

TABLE VI.—*Time required to exhaust in each soil mixture the water available for growth.*

Soil mixture No.	Mean electrical resistance.	Mean number of days from date of planting until wilting began.	Number of glasses in which wilting occurred.	Soil mixture No.	Mean electrical resistance.	Mean number of days from date of planting until wilting began.	Number of glasses in which wilting occurred.
1.....	200	18.0	6	8.....	81	27.0	6
2.....	165	18.0	6	9.....	76	27.6	5
3.....	136	19.3	6	10.....	72	31.5	6
4.....	122	22.0	6	11.....	65	33.4	5
5.....	111	25.0	6	12.....	62	36.0	2
6.....	99	23.5	6	13.....	59	38.7	4
7.....	89	24.3	6	14.....	55	43.5	2

CONCLUSIONS.

The results of this experiment make possible the following conclusions:

(1) The presence of an excess of soluble salts in a soil did not affect the ability of young wheat plants to reduce ultimately the water content of that soil to the wilting coefficient, unless the quantity of salts was sufficient to induce marked pathological symptoms in the plants.

(2) The time required for the exhaustion of the water available for growth increased steadily with increasing concentration of the soil solution (Table VI).

(3) The amount of growth made, so long as the moisture content of the soil remained well above the wilting coefficient, was determined by the concentration of the soil solution (Table IV).

(4) The presence of alkali increased the water requirement of the plants; in other words, increased the quantity of water transpired in

producing a unit weight of dry matter. The conditions of the experiment here described did not allow of accurate determinations of water requirement, but this conclusion seems unavoidable in view of the following facts: (*a*) Some of the plants in each soil mixture were able to reduce the moisture content to the wilting coefficient. Hence, practically the same total quantity of water was finally lost by transpiration from each soil. (*b*) The plants in the more strongly saline soils were much smaller when the wilting coefficient was reached than were those in the soils having a lesser salt content.

Experiments are now in progress to measure the effects of different quantities of alkali upon the water requirement of plants.

[Cir. 109]

INTERPRETING THE VARIATION OF PLAT YIELDS.¹

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FACTORS OF ERROR IN FIELD EXPERIMENTS.

All results obtained in field experiments are subject to errors the extent of which can not always be accurately determined by physical measurements. These errors may be due to a large number of causes, such as incorrect weighing of crop products, faulty determinations of plat areas, variations in the quantities of products recovered and wasted, unobserved variations in field treatment, etc. These are termed experimental errors, and the influence of some of them can be determined and controlled. Other important causes are individual plant variations, soil irregularities due to natural conditions or to nonuniform previous treatment, uneven distribution of soil moisture, temperature variations, etc. The influence of these factors can seldom be accurately determined or controlled. Frequently the total effect of all these causes is so great as seriously to influence the conclusions drawn from observed results, and if it is not taken into consideration the results may be badly misinterpreted. Where a large number of observations are made of results obtained under conditions which are uniform, except as they are affected by accidental error, the extent of that error can be calculated by a mathematical formula, and a part of the calculation results in what is known as the "probable error."

EXPERIMENTAL DETERMINATION OF THE PROBABLE ERROR.

FIELD TESTS IN NEBRASKA AND MONTANA.

In order to determine as nearly as possible to what extent these factors would influence the crop yields of plats to be used in the field experiments under irrigation at the Scottsbluff (Nebr.) and Huntley (Mont.) experiment farms, certain of the fields to be used were planted to uniform crops and given uniform treatment. In 1911 field K, at Scottsbluff, containing 66 quarter-acre plats, and field K, at Huntley, containing 68 quarter-acre plats, were planted to oats. At Huntley in the same year fields B II and B III, which are adjacent, and which contain 46 quarter-acre plats, were planted to sugar beets. In 1912 fields B II and B III, at Huntley, were planted to alfalfa. Ten adjacent quarter-acre plats were planted to alfalfa in 1912 in

¹ Issued Jan. 4, 1913.

field A II at Huntley. In each case the plats were harvested separately, and the yields obtained form the basis of the material presented in this paper.

The results obtained with 66 plats of oats on field K at Scottsbluff in 1911 will serve as an illustration of the method pursued. These plats received uniform treatment throughout the season, so that without a consideration of accidental errors it would be expected that the plat yields would be equal; or, in other words, it would be expected that the yield of any plat taken at random would fairly represent the yield of any other plat in the field. Such an expectation is, of course, never realized. It was found in the case of the oat plats at Scottsbluff that the yields varied from 372 pounds to 212 pounds—an extreme range of 160 pounds per plat. This variation is equivalent to 20 bushels per acre, or 55.7 per cent of the mean yield. Where a difference of 20, or even 10 or 5, bushels per acre is obtained from two plats receiving different treatments the difference is commonly considered significant and attributable to the treatments. But it is obvious that a difference of 5 bushels per acre would not have been significant on field K in 1911 if the oat plats had received different treatments.

It is commonly found that approximately one-half the results observed in a series will be greater than the mean of all the results and that approximately one-half the results will be less than the mean, and also that the number of results differing from the mean will decrease as the magnitude of the difference increases. For example, there are 29 plats in field K which yielded within 24 pounds of the mean yield, while only 10 plats differed from the mean yield by more than 48 pounds. Because of this tendency for the majority of the results to lie relatively close to the mean, the mean is taken as a basis upon which to calculate the probable error.

In a "perfect" series "*The probable error is such that, taking any single result at random, the chances are even for or against that result differing from the average by the amount of the probable error.*" In other words, half the results should differ from the mean by less than the probable error, the other half by more."¹

The probable error is calculated in the following manner: The mean of all the results is determined. This mean is subtracted from each result to obtain the difference, each difference is squared, and the sum of these squares, disregarding the sign, is found. Then the following formula is employed:

The probable error of a single result=

$$\pm 0.6745 \sqrt{\frac{\text{The sum of the squares of the differences.}}{\text{The number of results less 1.}}}$$

¹ Wood and Stratton. Journal of Agricultural Science (Cambridge), v. 3, pt. 4, p. 417. December, 1910.

The 66 plats at Scottsbluff are not a sufficient number to form a "perfect" series, where the variations are so great, but they afford an opportunity of calculating the probable error with sufficient accuracy for practical purposes. The mean yield of the 66 plats is 287 pounds and the probable error of any single result is found to be ± 23.9 pounds, or 8.3 per cent of the mean yield. This is equivalent to 3 bushels per acre. According to the above definition of probable error, 33 plats should yield within 23.9 pounds of the mean, and the yield of the other 33 plats should vary from the mean by more than 23.9 pounds. It was actually found that 29 plats varied from the mean by less than the probable error and 37 varied by more. While these numbers 29 and 37 are not equal, they are as close as can be expected in a series of only 66 observations and close enough for practical purposes.

The specific application of these determinations to field experiments is this: In a series of plats planted to a single crop and given uniform treatment marked variations may occur and from these variations the probable error may be determined. If, then, in the same series of plats later planted to a single crop and given *different* treatments, the variations in yield do not exceed the probable error as previously determined, these variations can not properly be attributed to the effects of the treatments and they should not be considered as significant. In other words, the probable error may be employed as a measure of the confidence which can safely be placed in experimental results. The more a variation, supposedly due to a treatment, exceeds the probable error the greater the confidence which can properly be placed in the supposition that the treatment is responsible for the variation. If a variation is greater than *twice* the probable error, its significance is very materially increased, and if it is so large as to exceed three, four, or five times the probable error, its significance approaches a practical certainty.

In the series of plats at Scottsbluff only ten plat yields varied from the mean by more than twice the probable error, and only four varied by more than three times the probable error. There were no variations from the mean equal to four times the probable error. In other words, to have obtained a variation equal to four times the probable error it would have been necessary to introduce a variation in the treatment. If under this different treatment a variation in yield greater than four times the probable error were obtained, it would be a practical certainty that the variation was due to the treatment. But any variation less than this would be subject to the suspicion that it might be due to accidental errors, such as soil irregularity, etc., rather than to treatment, and the suspicion would increase as the size of the variation decreased.

Table I contains the probable error determinations made on five groups of plats, one group at Scottsbluff, Nebr., and four at Huntley, Mont., together with some other data associated with the probable error in each case. Explanations of the various items are given after the table under the respective numbers of the items.

TABLE I.—*Probable error determinations made on five groups of field plats at the Scottsbluff and Huntley experiment farms.*

Items.	Groups.				
	A. 66 plats oats, Scotts- bluff field K, 1911.	B. 68 plats oats, Huntley field K, 1911.	C. 46 plats beets, Huntley fields B II and B III, 1911.	D. 46 plats alfalfa, Huntley fields B II and B III, 1912.	E. 10 plats alfalfa, Huntley field A II, 1912.
1. Mean yield (groups A, B, D, and E in pounds; group C in tons per acre).....	287	554	11.71	356	572
2. {Number of plats yielding above the mean.....	35	37	29	23	5
{Number of plats yielding below the mean.....	31	31	17	23	5
3. Extreme range of plat yields, expressed in percentage of mean yield of each group.....	55.7	106.0	67.9	52.5	51.5
4. Mean deviation of plat yields, expressed in percentage of mean yield of each group.....	9.8	22.5	12.9	12.5	9.6
5. Probable error of a single result expressed in terms of yield.....	±23.9	±105.95	± 1.29	±38.18	±49.27
6. Probable error, expressed in percentage of mean yield of each group:					
<i>a</i> Of any single result.....	± 8.3	± 19.1	±11.0	±10.7	± 8.6
<i>b</i> Of the average of 10 results.....	± 2.6	± 6.0	± 3.5	± 3.4	± 2.7
<i>c</i> Of the average of 20 results.....	± 1.9	± 4.3	± 2.4	± 2.4	.....
<i>d</i> Of the average of 30 results.....	± 1.5	± 3.5	± 2.0	± 1.9	.....
<i>e</i> Of the average of 40 results.....	± 1.3	± 3.0	± 1.7	± 1.7	.....
<i>f</i> Of the average of 46 results.....	± 1.2	± 2.8	± 1.6	± 1.6	.....
<i>g</i> Of the average of 66 results.....	± 1.0	± 2.34	.....	.....	.....
<i>h</i> Of the average of 68 results.....	.....	± 2.31	.....	.....	.....
7. Number of plat yields differing from mean:					
<i>a</i> By less than the probable error—					
Actual.....	29	26	25	19	6
Theoretical.....	33	34	23	23	5
<i>b</i> By more than the probable error—					
Actual.....	37	42	21	27	4
Theoretical.....	33	34	23	23	5
<i>c</i> By less than twice the probable error.....	56	63	38	38	7
<i>d</i> By more than twice the probable error.....	10	5	8	8	3
<i>e</i> By more than three times the probable error.....	4	0	4	0	1
<i>f</i> By more than four times the probable error.....	0	0	0	0	0

(1) The mean yield of each group of plats is expressed in pounds per plat, except in the case of group C, where, for convenience, it is expressed as tons per acre.

(2) This item is given to show how closely the plat yields in the different groups agree with the assumption that approximately one-half the results will exceed the mean. It is shown that in groups D and E the division is exactly equal; in A it is very close, and in B and C it is rather noticeably unequal. It should be stated that in group C, 7 of the 46 plats were spring plowed and the others fall plowed in preparation for beets. To this extent the treatment of the plats in group C was not uniform. The mean yield of the 7 spring-plowed plats was 0.83 ton per acre less than the mean yield of all 46 plats. The discrepancy introduces an error into the calculations, but it has only a very slight effect on the probable error.

(3) The extreme range in the yields obtained in each group is stated as a percentage of the mean yield of each group so as to facilitate comparisons among the groups. The extreme range in the plat yields at Scottsbluff was from 372 to 212 pounds per

plat, a total variation of 160 pounds, or 55.7 per cent of the mean yield. It will be noted that a high extreme range is closely associated with a high probable error.

(4) This item includes the mean of the deviations from the mean yield of each group expressed as a percentage of the mean yield. It will be noted that this is closely associated with and slightly greater than the probable error of a single result in each case.

(5) The probable error of a single result is first given in terms of yield. The probable error of ± 23.9 pounds in the case of group A means that if the yield of any plat in the group is taken at random the chances are even that the yield of such plat will be within 23.9 pounds of the mean yield of the group. It should be noted that the figure expressing the probable error is always *plus* or *minus*. Hence, while a result may vary from the mean by less than the probable error, it may be either greater or less than the mean.

(6) In order to facilitate comparisons the probable error is here stated as a percentage of the mean yield. The probable error in group A is ± 23.9 pounds of oats per plat, or 8.3 per cent of the mean yield. The probable error of ± 49 pounds of alfalfa per plat in group E is 8.6 per cent of the mean yield of that group. When reduced to a percentage basis the probable error of group A and that of group E are seen to be very nearly the same. The probable error of group C and that of group D are also extremely close. This fact is of special interest, because the fields used were the same in both cases—fields B II and B III, Huntley—while the crops were different and were, of course, produced in different seasons.

So far, the probable error of a single result, the yield of a single plat, has been considered. When the average of several results is taken, the probable error of that average is, of course, less than the probable error of one result. In other words, the average yield of 10 plats is likely to represent the mean yield of the group more nearly than does the yield of any single plat taken at random. The average yield of any 10 plats taken at random in group A will have a probable error of ± 7.59 pounds per plat, or 2.6 per cent of the mean yield, as compared with 8.3 per cent of the mean yield, the probable error of a single result. If, then, the number of results averaged be increased to 20, the probable error is still smaller—1.9 per cent of the mean yield in group A; and the probable error of the average grows continually smaller as the number of results averaged is increased, as is shown in the table. The fact that the probable error of the average of several results is less than that of a single result emphasizes the desirability of conducting field experiments in multiplicate. The probable error of an average can be obtained by dividing the probable error of a single result by the square root of the number of results averaged.

(7) Under this heading are given the number of plat yields differing from the mean by more or by less than the probable error or one of its multiples. Under *a* and *b* is given the number of results which, theoretically, should differ from the mean by more or by less than the probable error, as well as the actual number found. Theoretically, half the results should differ from the mean by less and half by more than the probable error. The table shows that the actual results are in the main reasonably close to the theoretical requirements. They are as close as can be expected where such small numbers of results are considered. Under *d*, *e*, and *f* it is seen that comparatively few plat yields differ from the mean by more than twice the probable error, still fewer by more than three times, and none by more than four times the probable error. Hence, it may be expected that on these fields accidental variations as great as four times the probable error are not likely to occur; so that when different treatments are applied and variations greater than four times the probable error are obtained, such variations can be attributed to the treatments with a high degree of certainty.

FIELD TESTS IN ENGLAND.

Wood and Stratton, of Cambridge, England, have published some results relative to the probable error of field experiments. Their investigations covered numerous observations on wheat, barley, oats, mangels, potatoes, and other crops. They observed that there was no significant difference between the probable error of one of these crops and that of any other. This is in a way supported by the close agreement found at Huntley with sugar beets and alfalfa, groups C and D, *where the same field was used for both trials*. But Wood and Stratton take 5 per cent as the probable error of a single plat in carefully conducted field experiments.¹ The facts that at Huntley and Scottsbluff widely different probable errors were found for the same crop (oats) and that the probable errors determined at the two farms are considerably greater than 5 per cent indicate that to take 5 per cent as "the probable error of field experiments" is not generally justified.

CONCLUSIONS.

The material here presented may be used to emphasize the following points:

(1) Probable error determinations are valuable as a measure of the reliability of results of field experiments and of the confidence which may properly be placed in conclusions drawn from such results.

(2) The value of experiments would be greatly increased if the probable error applicable to the field were determined in advance; and where the experiments contain several plats receiving the same treatment it is desirable to determine each year the probable error of the results obtained on such plats, as in this way the effect of seasonal factors on the probable error may be estimated.

(3) In conducting field experiments all possible precautions should be taken in order to minimize accidental errors.

(4) It is always desirable to conduct tests in duplicate, so as to be able to compare averages rather than single results.

(5) In interpreting and publishing experimental results the probable error should be given consideration; otherwise, insignificant differences may be unduly emphasized.

¹ "The probable error of field experiments is investigated by two independent methods, and found to be about 5 per cent of the crop."—*Journal of Agricultural Science (Cambridge)*, v. 3, pt. 4, p. 440. December, 1910.